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Forest Management Decision Model Based on the Entropy Weight and Coefficient of Variation Method

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Abstract: *To measure the carbon sequestration capacity and other benefits of forests and to determine an optimal forest management plan, we build the Forest Management Decision Model. Firstly, we establish a Carbon Sequestration Model. We calculate the amount of carbon dioxide sequestration from three aspects of standing forest, soil, and forest products. Then, to balance forest carbon sequestration with other benefits brought by forests, we establish a forest management decision model and introduce the concept of Forest Value Index (FVI). We select 10 indicators closely related to forest value from 4 perspectives. The indicators are integrated into the FVI using the entropy weight method (EWM) and the coefficient of variation method (CVM), combined with the model constructed, to assist forest managers in making management decisions.*

Keywords: *Carbon sequestration; Forest management; EWM; CVM*

1. Introduction

For the sake of understanding the carbon sequestration capacity of forests and making the best decision for forest management in combination with their other benefits, it is necessary to establish a model based on the evaluation of forest management system values. By selecting appropriate evaluation indicators, assigning weights to indicators, and combining low-level indicators, comprehensive indicators are calculated. Subsequently, the established model was applied to forests in various regions, its applicability is tested, and revisions are proposed to improve the model.

2. Model establishment and solution

2.1. Carbon Sequestration Model

To figure out the carbon dioxide a forest and its products can be anticipated to sequester over time, we divide the sequestration roles of the whole forest system into the following aspects according to distinct characteristics, where $C_{forest\ system}$, C_{sf}, C_s, C_{fp} correspondingly stand for the carbon sequestration by the forest system, standing forests, soil, and forest products.

$$C_{forest\ system} = C_{sf} + C_s + C_{fp} \tag{1}$$

$$C_{CO_2} = \frac{44}{12} \times C_{forest\ system} \tag{2}$$

Where C_{CO_2} represents the carbon dioxide sequestration by the forest system.

2.1.1. Carbon sequestration calculation

(1) Standing forest sequestration

The carbon stocks of forests can be calculated from the biomass, carbon fraction, and the stand area of these plants.

$$C_{sf} = \sum_{k=1}^{n} (B_k \times CF_k \times S) \qquad k = 1, 2 \cdots, n \tag{3}$$

The biomass of plants in forests can be divided into above-ground biomass and below-ground biomass.

$$B = B_{AGB} + B_{BGB} \tag{4}$$

Above-ground biomass refers to the weight of all living plants above the ground in terms of dry weight, which can be calculated from the accumulation per unit area, tree trunk density, and biomass expansion factor.

$$B_{AGB} = \sum_{k=1}^{n} (V_k \times D_k \times BEF) \tag{5}$$

The biomass expansion factor is an important estimation parameter, which is mainly used for the conversion between the trunk biomass and the total biomass of the forest and the biomass of each dimension. Considering that BEF is dynamic, it is closely related to forest type, forest age, biological characteristics such as tree growth and development, as well as site conditions, stand conditions, and other factors. To this end, Fang Jingyun used the reciprocal equation to express the relationship between BEF and V, where a and b are constants under a specific forest type [2].

$$BEF = \sum_{k=1}^{n} a + \frac{b}{V_k} \tag{6}$$

It can be obtained from equation (6) that when the tree is in its young stage, the value of V is small, and the BEF is large. When the tree is in its mature stage, the value of V is very large, and the BEF tends to the constant value a. This reasoning is in line with the biological correlation growth theory. Combining the equation (5) and (6), we can obtain the following expression:

$$B_{AGB} = \sum_{k=1}^{n} D_k \times (a \times V_k + b) \tag{7}$$

Below-ground biomass is the weight of all living plants below the surface-expressed as dry weight. The root-shoot ratio refers to the proportion of the fresh or dry weight of the underground part to the aerial part of the plant. Its size reflects the relationship between the underground and above-ground parts of the plant. Therefore, we introduce the root-shoot ratio (RSR) to calculate the below-ground biomass.

$$B_{BGB} = B_{AGB} \times RSR \tag{8}$$

(2) Soil carbon sequestration

$$C_s = \sum_{k=1}^{n} (SOCC_k \times S_k) \qquad k = 1, 2, \cdots, n \tag{9}$$

(3) Forest products sequestration

$$C_{fp} = \sum_{i=1}^{4} (V_i \times D_i \times CF_i) \qquad i = 1, 2, 3, 4 \tag{10}$$

Where *V, D, i* respectively represent volume, basic density, and different categories. We assume that the carbon storage of forest products does not decay during the lifetime, and the carbon storage at the end of the life is recorded as 0.

$$C_t = \frac{1}{1+f} \times (C_{t-1} + C_t) \tag{11}$$

Where *f and* C_t respectively represent the decomposition rate of the products and the carbon sequestration of forest products in year *t*.

2.2. Carbon Sequestration Management Model

The ability of trees to fix carbon dioxide has a strong linear relationship with their biomass. Therefore, the trend of tree biomass change with tree age can be simulated by the Logistic regression analysis model.

$$B_n = \frac{A}{1 + me^{-kn}} \tag{12}$$

where B_n is biomass, *A* is biomass at maturity, *m* is the model parameter, *n* is time, *and k* is the exponential growth rate of biomass.

We simply divide tree types into A (planted forest) and B (primary forest and other naturally regenerated forests). As the total forest area and carbon content rate are assumed to remain unchanged, and the carbon sequestration capacity of mature trees is presumed stable, the relationship between carbon sequestration capacity and tree age is shown in 0

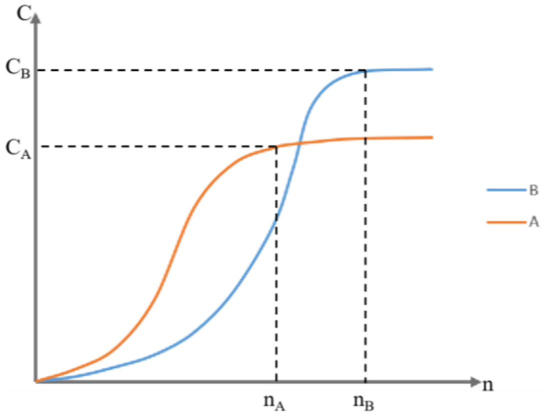

Figure 1: Growth curves of different tree species

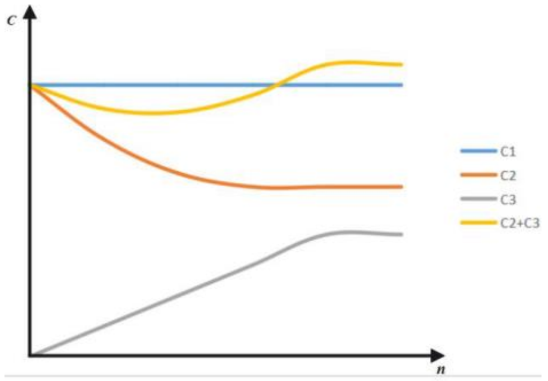

Figure 2: Change of carbon sequestration under different management conditions

It can be seen from 0that the mature age n_A of planted forests is significantly shorter than that of primary forests and other naturally regenerated forests n_B. However, the carbon sequestration ability C_A of artificial fast-growing forests is smaller than that of primary forests and other naturally regenerated forests C_B after maturity. Hence, we can conclude that cutting and replanting planted forests is more cost-effective and better for carbon sequestration than primary forests and other naturally regenerated forests.

As the growth rate of biomass decreases significantly after trees maturity, the benefits of carbon sequestration are reduced. Therefore, we confirm the time when the trees are just mature as the best harvesting time cycle.

After determining planted forests as the choice to harvest, it is time for the comparison of carbon dioxide sequestration capacity between no harvesting and moderate harvesting. We assume that the total area of fast-growing plantations managed is S and every tree is mature. Then the annual carbon sequestration C_1 of the uncut forest is constant. In addition, we suppose B_A to be the biomass of the mature forests.

$$C_1 = B_A \times S \times CF \tag{13}$$

We suppose i to be the year in which moderate harvesting begins, and the same area S_0 of the forest is cut down every year and made into forest products. For sustainable forest management, we need to ensure that mature planted fast-growing forests are available for felling every year [4]. Therefore, the relationship between S and S_0 is expressed in the formula:

$$S = n_A \times S_0 \tag{14}$$

When $1 \leq i \leq n_A$, the annual change of forest carbon storage C_2 is:

$$The\ i^{th}\ year\!: \ C_2 = \left[\sum (B_1 - B_i) + B_A \times (n_A - i)\right] \times S_0 \times CF \tag{15}$$

When $i \geq n_A$, the annual carbon storage C_2 of the forest is constant:

$$The\ i^{th}\ year\colon\ \ C_2 = \sum (B_1 - B_A) \times S_0 \times CF \tag{16}$$

Since the same area of S_0 mature forest is harvested every year, the carbon sequestration of forest products made after felling keeps constant. Considering the loss in the production of forest products, we introduce δ to calculate the proportion of forest products in the biomass of harvested trees.

$$C_{fp} = \delta \times B_A \times S_0 \times CF \tag{17}$$

We suppose n_c is the average lifespan of forest products, the carbon storage C_3 of forest products can be expressed as follows:

$$when\ 1 \leqslant i \leqslant n_c,\ \ C_3 = C_{fp}\ \ \times i\ ,when\ 1 \geqslant n_c,\ \ C_3 = C_{fp}\ \ \times n_c \tag{18}$$

The trend chart comparing the carbon storage C_1 of the no-cutting management scheme and the carbon storage C_2+C_3 of the moderate felling management scheme is shown in Figure 2. In the beginning, the carbon sequestration of forests gradually decreased after harvesting and the accumulation of carbon storage of forest products was limited, $C_1>C_2+C_3$, which means that the plan without felling has a better ability to sequester carbon dioxide. However, the carbon storage of moderate harvesting and forest products gradually increases and stabilizes with time going by. After n years, $C_1<C_2+C_3$, which reflects that the management plan of moderate harvesting is more effective in sequestering carbon dioxide.

2.3. Forest Management Decision

A rational forest management plan is developed to measure the comprehensive value of the forest. We constructed the forest value management index, which is abbreviated as FVI. We select ten three-level indicators from four perspectives primarily as the scope of the forest management plan, as shown in Table 1.

2.3.1. Weight of indicators

(1) Entropy weight method

These ten metrics of $X_1, X_2, X_3, \cdots, X_{10}$, where $X_i=\{x_{i1},\ x_{i2},\ \cdots,\ x_{in}\}$, illustrate the effects of the forest management plan. After data standardization, y_{ij} can be used to substitute for x_i to describe the forest management plan. In the light of the concept of self-information and entropy in information theory, the information theory e_i of each index can be figured out, and hence

$$e_i = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}),\quad p_j = \frac{y_{ij}}{\sum_{j=1}^{n} y_{ij}} \tag{19}$$

The weight of each evaluation metric defined above can be further calculated.

$$w_i = \frac{1-e_i}{m - \sum_{i=1}^{m} e_i} \qquad i = 1, 2 \cdots,\ \ m \tag{20}$$

Additionally, four comprehensive evaluation indicators of carbon sequestration benefits, other ecological benefits, economic benefits, and social benefits are obtained. We will abbreviate them as CSI, OEI, EI, SI.

$$\begin{cases} CSI = w_1 y_{1j} + w_2 y_{2j} + w_3 y_{1j} \\ OEI = w_4 y_{4j} + w_5 y_{5j} \\ EI = w_6 y_{6j} + w_7 y_{7j} \\ SI = w_8 y_{8j} + w_9 y_{9j} + w_{10} y_{10j} \end{cases} \tag{21}$$

(2) Coefficient of variation method

To directly appraise the forest management plan, we subsequently aggregate these four indicators into a composite indicator. We take the coefficient of variation method (CVM) into consideration, which can directly use the information contained in each exponent to obtain the weight of the index through calculation. As the differences exist between the four comprehensive indicators and the mean, the ratio of the standard deviation to the mean is used instead of the standard deviation. The equation for each index can be expressed as:

$$W_i = \frac{C.V_i}{\sum_{i}^{n} C.V_i} \qquad i = 1, 2, 3, 4 \tag{22}$$

Then the forest value management indicators (FVI) can be acquired.

$$FVI = (W_1 \times CSI + W_2 \times OEI + W_3 \times EI + W_4 \times SI) \times 100 \tag{23}$$

We can calculate the FVI with the specific value of the metrics given in Table 1. As we can see, the weight distinctions do exist between the ten indicators, which fluctuate between 0.2 and 0.6. Biodiversity has the largest weight of 0.5870 while living quality has the smallest weight of 0.2307. The same goes for secondary indicators, among which economic benefits win the first prize with the weight of 0.2912, while social benefits take the last place.

Table 1: Weight values of the ten evaluation indicators and four comprehensive indexes

Indicators (I)	Indicators (II)	Weights	Indicators (III)	Weights
Forest value management	Carbon sequestration benefits	0.2469	Carbon sequestration potential	0.4331
			Forest area	0.3135
			Forest biomass	0.2534
	Other ecological benefits	0.2550	Biodiversity	0.5870
			Soil lifespan	0.4130
	Economic benefits	0.2912	Forest rent	0.4143
			Forestry Employment	0.5857
	Social benefits	0.2070	Environment education	0.5185
			Psychological health	0.2508
			Living quality	0.2307

3. Model Evaluation

The model selects reliable and accurate data, and the research results have a high reference value. The model comprehensively considers the effects of forest structure, tree age, tree species, and other factors on forest carbon sequestration capacity. We determine the evaluation indicators from four aspects: carbon sequestration, ecological benefits, economic benefits, and social benefits, which can objectively describe the value of a forest.

We ignore the carbon dioxide released during the harvesting and processing of forest products, which may reduce the accuracy of the model.

References

[1] Tanzeel Javaid Aini Farooqi, Xuhua Li, Zhen Yu, Shirong Liu, Osbert Jianxin Sun. Reconciliation of research on forest carbon sequestration and water conservation [J]. Journal of Forestry Research, 2020, 32 (pre-publish).
[2] D. E. KNUTH The TEXbook the American Mathematical Society and Addison-Wesley Publishing Company, 1984-1986.
[3] Latifah S, Purwoko A, Fachrudin K A, Dahriyanti N S T. Types and benefit of nontimber forest product for the community around the forest [J]. IOP Conference Series: Earth and Environmental Science, 2021, 782 (3).
[4] Olivia Cintas, Göran Berndes, Annette L. Cowie, Gustaf Egnell, Hampus Holmström, Gregg Marland, Göran I. Ågren. Carbon balances of bioenergy systems using biomass from forests managed with long rotations: bridging the gap between stand and landscape assessments [J]. GCB Bioenergy, 2017, 9 (7).
[5] Pilli Roberto, Vizzarri Matteo, Chirici Gherardo. Combined effects of natural disturbances and management on forest carbon sequestration: the case of Vaia storm in Italy [J]. Annals of Forest Science, 2021, 78(2).